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A MICROSCOPIC STUDY OF THE IPSWICH COALS

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CONTENTS.

1. INTRODUCTION.

Economically important deposits of coal in Queensland range in rank from semi-anthracite to lignite, in type from bright to splint, and in geological age from Permian to Tertiary. In the face of such variation in rank and type caused by differences in origin and in metamorphic evolution it is evident that as many lines of evidence as possible should be utilized in order to appreciate the suitability of the different coals for various industrial purposes. However, scientific information on the nature of these coals has previously been mainly restricted to proximate chemical analyses and determinations of calorific values, and no previous work has been carried out on their micro-structure.

The present work aims at elucidating quantitatively the microscopic composition of coal from the major seams mined in the Ipswich Coalfield in order to provide a basis for comparison with other Queensland coals. A brief summary of the results obtained has already been published (de Jersey, 1944). The more difficult problems to be overcome in the course of the work were those involved in the technique of preparation of thin sections of coal. The preparation of micro-sections of coal sufficiently thin to be studied by transmitted light requires considerable practice and experimentation to develop suitable methods. The normal petrographic technique for the preparation of thin sections of rocks cannot be applied as the normal thickness of a coal micro-section, which is 3 microns (.003 mm.), is one tenth of the normal thickness of a rock section. For the preparation of the thin sections used in this investigation, the main outlines of the method described by Raistrick and Marshall (1939, pp. 266-269) have been followed with some modifications which have been due in part to the brittle nature of some of the Ipswich coals. Among these may be mentioned the use of a high quality Canada balsam instead of the mounting medium used by Raistrick and Marshall. It is necessary to mount the sections at as low a temperature as possible in order to avoid the formation of gas bubbles from the coal; the coal selected for sectioning should be unweathered and free from cracks in the area of the section.

All the thin sections prepared are vertical sections cut perpendicular to the bedding of the coal seams; such sections yield far more information regarding the nature and proportions of the constituents than horizontal sections. With regard to the nomenclature of the coal constituents or macerals the American system has been adopted in preference to the British terminology as it has been more successfully applied to the quantitative description of coal seams. A detailed account of the American terminology is given in the classic paper of Thiessen and Sprunk (1935, pp. 2-11). The four constituents—anthraxylon, translucent attritus, opaque attritus and fusain—have been identified in the Ipswich coals and their proportions may be estimated quantitatively without serious difficulty.

Although the following descriptions are based largely on thin sections, some polished sections have been prepared and such polished surfaces have been found useful with regard to interpretation of the macroscopic appearance of the coals.

2. PETROGRAPHIC DESCRIPTIONS.

The coal seams of the Ipswich Series are divisible into two groups which correspond to two distinct stratigraphical stages:—the Tivoli and Blackstone Stages. The former, which comprises the lower part of the series, is developed in the North Ipswich district, while the Blackstone Stage comprises the remainder of the series developed in the Bundamba district. In the following detailed descriptions the coal seams of the Blackstone Stage are considered first, and are dealt with in descending stratigraphical order.

(a) THE COAL SEAMS OF THE BLACKSTONE STAGE.

(i) The Aberdare Seam.

(Plate 3, fig. 1.)

Specimens of coal from several collieries working this seam have been collected and studied; the coal from Hart's Aberdare Colliery has been selected for detailed microscopic study.

Macroscopic Appearance.

This coal appears to be uniformly bright on the fracture surfaces of hand-specimens; examination of polished surfaces, however, shows the presence of thin layers of attrital material which have a grayish appearance. The average thickness of the bright bands of anthraxylon indicates the finely banded nature of the coal. The vertical cleavage surfaces produced by cleat are separated by intervals of 3 to 5 mm. and fracture parallel to the bedding is poorly developed in comparison with the vertical cleat so that specimens of considerable vertical extent can be secured.

Microscopic Composition.

An average petrographic analysis of the Hart's Aberdare coal is as follows:—

	Per cent.
Anthraxylon	86
Translucent attritus	0.5
Opaque attritus (including brown matter)	12
Fusain	1.5

The anthraxylon, which is red in sections of normal thickness, occurs in bands ranging in thickness from over 2 mm. to under ·05 mm. As Thiessen and Sprunk (1935, p. 8) define the range for a finely banded coal as from 0·2 to 2 mm., and for a microbanded coal as less than 0·2 mm., this must be classed as a microbanded to finely banded coal. Although indications of cell structure can be seen in nearly all the bands, the preservation is generally poor and the general nature of the anthraxylon suggests that it was in an advanced state of decomposition and maceration when in the peat stage. While the structure is not well enough preserved for identification, indications of circular pits can be seen in various areas of vertical sections. In one area a structure which is identifiable as the annulus of a sporangium can be seen in cross section. It consists of several layers of cells of varying size which have yellow cell walls and cell cavities filled by dark brown coal substance. There is a similarity in general appearance to sporangia and annuli figured by Thiessen and Sprunk (1941, figs. 35, 36).

The attritus in this coal consists mainly of brown-opaque matter, that is, material which appears practically opaque in sections of normal thickness but is brown and translucent in very thin sections. Thiessen and Sprunk call this "brown cell-wall degradation matter" or "brown matter." It occurs in the Aberdare coal as thin lenticles and larger bands which are also lenticular. The translucent attritus, which forms only a small poportion of the coal, is composed mainly of fragments of cuticular matter, with spores, resin fragments, and indeterminate particles. The predominate spores are microspores, which are mainly smooth, thin-walled types, while the few megaspores seen are smooth and thick-walled. The fusain occurs in bands or lenticles with cell structure occasionally moderately well preserved.

The anthraxylon bands are anisotropic and show extinction under crossed nicols approximately parallel and at right angles to the bedding. In this respect the anthraxylon is similar to that of the other coals of the Blackstone stage. Interference colours are masked by the normal red colour of the anthraxylon.

(ii) The Bluff Seam.

(Plates 1, 2.)

Specimens of coal from this seam selected for study came from Box Flat Extended No. 5 Colliery.

Macroscopic Appearance.

This coal is fairly uniform in appearance as the banding is too fine to be easily distinguishable by macroscopic examination. In general it is not as bright as the Aberdare coal. At intervals there occur thin layers (up to 1 cm.) of brighter material which is also more friable; these properties suggest that they are richer in anthraxylon than the remainder of the coal and this has been confirmed by study of thin sections. These layers comprise approximately 15 per cent. of the coal. Specimens of coal tend to fracture along these bands on account of their greater friability. Particles of pyrite are visible on the fracture surfaces and reach a diameter of 1·5 mm. Thin lenticular streaks of carbonaceous shale also occur in typical specimens of this coal.

Microscopic Composition.

An average petrographic analysis of the coal is as follows:—

	Per cent.
Anthraxylon	67
Translucent attritus	1
Opaque attritus (including brown matter)	16
Fusain	16

The anthraxylon is finely banded to microbanded. The layers range in thickness down to extremely thin shred-like strands; these thinner strands have a fibrous appearance and grade into attritus. The crooked and frayed nature of the thinner bands of anthraxylon is a feature in common with the splint coal type and with the high proportion of attritus, composed essentially of brown matter and granular opaque matter, suggests that the coal should be classified as a semi-splint type. Included in the anthraxylon are rounded particles of pyrite which are quite variable in size but average approximately 0·1 mm. in diameter.

Quantitative data show that brown cell wall degradation matter, granular opaque matter and fusain predominate in the attritus. The first two of these occur in approximately equal proportions in the material determined as opaque attritus. Some of the fusain occurring in small granular fragments is difficult to distinguish from the granular opaque matter of the attritus and these constituents are probably similar in chemical composition. The translucent attritus consists of fragments of cuticles and thin-walled microspores with irregular outlines in approximately equal proportions as well as a considerable proportion of indeterminate plant degradation matter. There is a considerable amount of translucent mineral matter occurring as particles of small grain size in the attritus.

Microscopic examination indicates that this coal has a high proportion of mineral matter, which comprises particles of pyrite in the anthraxylon, thin shale streaks and small particles of translucent mineral matter in the attritus. This is confirmed by chemical analyses which show an ash content of approximately 20 per cent.

(iii) The Four-foot Seam.

(Plate 3, fig. 2; plate 4, fig. 2; plate 5, fig. 2.)

Coal from the Four-Foot seam which was studied in detail came from Bonnie Dundee No. 2 Colliery. This coal is a mixture of the bright and splint types in the proportion of 75 per cent. of bright to 25 per cent. of splint coal.

Macroscopic Appearance.

In contrast to the finely banded or microbanded coals studied from other seams in the Blackstone stage, this coal is coarsely banded and the banding is thus easily distinguishable with the naked eye. The anthraxylon and attritus occur in thick bands and the coal may thus be considered as a mixture of two types: (1) Bright coal composed predominantly of anthraxylon and (2) Splint coal composed predominantly of attritus. The bright coal occurs in elongate lenses which range up to 1·5 cm. in thickness. Its even bright lustre indicates that it is highly anthraxylous, and this is confirmed by quantitative study of thin sections. It is more highly cleated and more friable than the splint coal.

The splint coal has a dull, steel-grey appearance on fracture surfaces, and shows little indication of banding except for thin, irregular strands of anthraxylon. It is harder and tougher than the bright coal and breaks into sharp-edged blocks.

Microscopic Composition.

The coal from Bonnie Dundee No. 2 Colliery has the following average petrographic analysis:—

	Per cent.
Anthraxylon	75
Translucent attritus	5
Opaque attritus (including brown matter)	18
Fusain	2

Detailed descriptions of the two types present, bright and splint, are given separately below.

Bright Coal.

An average petrographic analysis of the bright coal is:—

	Per cent.
Anthraxylon	95
Translucent attritus	2
Opaque attritus	2
Fusain	1

This coal is distinctive in that it contains a considerable proportion of leaf degradation matter; material which can be definitely identified as derived from leaf tissues is abundant in some layers of the seam. The anthraxylon throughout shows indications of cell structure, but in some cases structure is particularly well preserved. The better preserved examples appear to be representative of xylem from the vascular leaf tissue; in cross section the cells appear compressed and their lumina are occupied by dark reddish-brown coal substance. The ovoid shape of some of the cell aggregates is suggestive of compressed vascular bundles. A proportion of resinous matter, especially of the large resin-duct type is present and similar material has been identified as being of Pteridospermic origin in American coals. Other examples of well-preserved cell structure are suggestive of various internal leaf tissues and their frequent association with cuticles confirms this.

The attritus, both translucent and opaque, occurs as lenticular patches in the anthraxylon. The translucent attritus is composed very largely of cuticles and fragments of cuticular matter. They are variable in appearance and range from thick, bright yellow types down to thin, almost colourless cuticles resolved only under high magnification. Also present are smooth microspores. Opaque attritus occurs as thin strands associated with the other attrital matter. Some of this material may represent finely divided fusain, but a portion of it is definitely brown matter. The fusain occurs as lenticular fragments with the cell cavities filled with mineral matter.

The particles of mineral matter present are distributed rather uniformly through the coal and have an average diameter of 10 microns. A proportion of mineral matter also occurs as the in-filling of shrinkage cracks perpendicular to the bedding. A similar occurrence has been noted in the Indiana No. 4 Bed coal of the United States, in which "the kaolinite is found as filling in small vertical cleats or cracks in the anthraxylon bands, rarely in the duller or attrital portion, and was evidently deposited in the shrinkage cracks formed in the early stages of coalification." (Fieldner and others, 1938, p. 18.)

The anthraxylon in this coal is extinct under crossed nicols at angles of less than 3 deg. to the bedding and thus resembles the other Bundamba coals in its polarisation properties.

Splint Coal.

An average petrographic analysis of the splint coal is:—

	Per cent.
Anthraxylon	14
Translucent attritus	14
Opaque attritus (including brown matter)	68
Fusain	4

Thin sections of the splint coal are distinctive in general appearance under low magnification, as they are characterised by the predominance of semi-opaque and opaque matter, as contrasted with the greater proportion of translucent material, represented by anthraxylon and translucent attritus, in the bright coal. The anthraxylon occurs in the form of thin, irregular, frayed strands and often has cell structure (of the xylem tissue type) fairly well preserved; even the thinnest shreds show some indications of cell structure. The translucent attritus consists very largely of translucent humic matter; this consists of fragments of tissues of variable size and shape which are dark red or brownish red in colour. Some of the dark red fragments show cell structure and are probably of parenchymatous origin; in other cases association of humic matter with cuticles indicates that it is derived from leaf tissues. The remaining translucent matter consists of microspores and fragments of cuticles. The material included as opaque attritus is seen to be essentially composed of brown matter which appears almost opaque in sections of normal thickness, but is brown in colour in very thin sections; the transition of frayed edges and shreds of anthraxylon bands into brown matter indicates rather clearly the origin of most of the brown matter by decay of the vascular anthraxylon strands. This is in agreement with recent American work on the origin of splint coals. (Sprunk and others 1940, pp. 22-28.)

Splint coals are considered to owe their origin to flooding of the coal swamps with fresh oxygenated water, thus sweeping out part of the stagnant, more nearly toxic water and improving conditions for the action of biological agencies. Such conditions favour more complete decay and disintegration of the plant tissues. The biological agents of decay are principally bacteria, and in thin sections of this splint coal rounded bodies 2·5 microns in diameter are associated with decayed portions of the anthraxylon bands and are suggestive of bacteria. The remaining constituent, fusain, occurs as small lenticles with empty cell cavities.

Splint coals often contain considerable mineral matter, brought in by the streams draining into the coal swamp and responsible for the wet environmental conditions outlined above. The Four-Foot seam is no exception in this respect, and microscopic study suggests that the greater part of the ash content of the seam (apart from the larger shale bands) is associated with the splint coal. Particles of mineral matter are disseminated through the attritus and range from a diameter of 5 microns down to extremely small fragments. The larger part of the mineral matter, however, occurs in the form of shale streaks and lenses several millimetres in thickness. They are made up of very fine-grained particles of Kaolinite and contain fragmented strands, shreds and particles of anthraxylon which are arranged in similar fashion to those in a splint coal. Lenticles of fusain are also abundant in these shale lenses. One thin section of the splint coal was estimated to contain approximately

25 per cent. of mineral matter, largely in the form of shale streaks and lenses. This carbonaceous shale cannot be easily distinguished from the splint coal by its macroscopic appearance.

(iv) Bergin's Seam.

Coal from this seam which was studied microscopically came from No. 2 tunnel, Noble Vale Colliery. It was difficult to prepare thin sections of this coal on account of its rather friable nature and tendency to develop cracks during the process of sectioning. However, sufficient information is available to demonstrate its type and to obtain a fairly accurate knowledge of its petrographic composition.

Macroscopic Appearance.

A proportion of the coal is made up of bands of bright, highly cleated and friable material which has a considerably higher anthraxylon content than the remainder, which is duller, less friable and appears fairly finely banded. On the vertical fracture surfaces cracks are closely spaced and represent cross-fracture at right angles to the cleat.

Microscopic Composition.

The average petrographic analysis of the available thin sections of this coal is:—

	Per cent.
Anthraxylon	63
Translucent attritus	2
Opaque attritus	25
Fusain	10

The thickness of the anthraxylon bands falls within the limits for a finely-banded coal. They are more or less straight, compact and smooth, in contrast to their irregular nature in splint coal. In general, cell structure is poorly preserved although some thin layers occur showing cell structure with the cell walls compressed and the cell cavities distorted in shape.

The material determined as opaque attritus consists of granular opaque matter and brown matter. Fusain occurs in the form of lenticles in which the cell walls are opaque and cell structure poorly preserved. Some of this material in the finely disintegrated state is difficult to distinguish from the granular opaque matter of the opaque attritus. The translucent attritus consists mainly of fragments of cuticular matter and cuticles, the remainder consisting largely of microspores, which are smooth and thin-walled. Megaspores are quite rare in this coal.

Mineral matter occurs in the thin sections as fragments of small grain size disseminated through the bands and lenticles of opaque attritus.

(v) The Rob Roy Seam.

(Plate 5, fig. 1.)

Thin sections of coal from this seam were made from a seam column collected from Rylance No. 3 Colliery. A. K. Denmead has correlated the seam now worked in this colliery with the Rob Roy seam.* The seam is composed very largely of bright coal, and has a few thin layers of splint coal which are mainly associated with shale bands.

* Verbal Communication.

Macroscopic Appearance.

The bright coal contains bands which vary in friability, the more friable bands, which are evidently richer in fusain, being more pronounced near the top of the seam. The bands of splint coal are sharply differentiated and readily distinguishable underground. They have the typical dull, greyish appearance and tough, poorly cleated nature of this coal type.

Microscopic Composition.

The average petrographic analysis of the seam is:—

	Per cent.
Anthraxylon	83
Translucent attritus	1
Opaque attritus	10
Fusain	6

Bright Coal.

The coal is finely banded to microbanded. The anthraxylon consists predominantly of material showing indications of its original cell structure and the cell walls are often quite distinct. It is mainly composed of alternating lighter and darker layers. In the lighter layers the tissues consist of cells with lighter cell walls and cell cavities filled with darker brownish red cell contents, while in the narrower darker layers the cell walls are much compressed and the cell cavities are reduced to very thin linear strips. Also occurring in some layers are lenticular fragments of tissue with the cell structure particularly well preserved. Their yellow colour in thin section suggests that they are resinous in nature. The cells are thin-walled and mainly equidimensional.

This coal differs in its spore content from the other seams of the Blackstone stage. The translucent attritus consists largely of megaspores and microspores while in the other coals cuticular matter predominates. The megaspores are of several types and comprise some forms which are simple in shape and others which have wing-like projections. They are of average length 0·5 mm. The microspores have an average length of 60 microns. Cuticles and fragments of cuticular matter occur in small proportions and are often associated with anthraxylous tissues for which a leaf origin is thus indicated.

The opaque attritus occurs in thin shreds associated with the other attrital matter. In general the attritus is associated with some anthraxylon in thin bands and lenticles in which its proportion is consequently higher than in the thicker anthraxylon bands. Some lenticles of fusain are also present.

Mineral matter consists of particles scattered rather irregularly through the coal, but tending to a much higher proportion in certain bands, which would contain over 10 per cent. sedimentary mineral matter. The particles are of varying grain size, the average diameter being of the order of 5 microns, while some are so small as to be resolved only under high magnification. Some mineral matter also occurs filling shrinkage cracks in the anthraxylon bands.

Splint Coal.

The layer of splint coal sectioned has the following average petrographic analysis:—

	Per cent.
Anthraxylon	9
Translucent attritus	23
Opaque attritus (including brown matter)	67
Fusain	1

This layer is sharply limited from the bright coal of the seam, the complete transition between the two types being visible within the limits of one microscopic field. The anthraxylon consists of the thin irregular strands typical of splint coal. All the strands show cell structure moderately well preserved. The material determined as opaque attritus is almost entirely brown matter, which consequently constitutes the bulk of the coal. It shows all degrees of translucence and is brown in colour in very thin sections, being practically opaque in sections of normal thickness. A small proportion which remains opaque in very thin sections consists of granular opaque matter. Fusain occurs in lenticles and bands with mineral matter occupying the cell cavities.

A noteworthy feature of this layer is the abundance of spores; it may, in fact, be termed a spore-rich splint coal. The microspores are nearly all thin walled and often have projections suggestive of wings. They are of similar size to those described from the bright coal. Some megaspores are also present and are similar to those in the bright coal. The remainder of the translucent attritus consists of lenticles of translucent humic matter which are dark red in thin section. Many of them show well preserved cell structure; the cell walls are thin and they are probably of parenchymatous origin. Mineral matter occurs in particles of very variable grain size, reaching 0·1 mm. in diameter and ranging down to 1 micron or less, and also in shale streaks and lenticles. Some quartz is present as well as kaolinite.

(vi) Other Seams

In addition to the above seams, coal from the "New Found Out" seam worked in Aberdare Extended Colliery has been studied in detail. There is some stratigraphical evidence to indicate that this seam is on a higher horizon than the Aberdare seam. The coal itself is so distinctively different from specimens of the Aberdare coal studied as to support this view. In particular, fusain, which forms only a small proportion of the Aberdare coal, is present in sufficient quantity to have a marked influence on the character of the coal. It occurs in bands and lenses reaching one centimetre in thickness. This material is comparatively soft and its presence in quantity renders the coal much more friable than that from the Aberdare seam. The average petrographic analysis is:—

	Per cent.
Anthraxylon	74.5
Translucent attritus	0.5
Opaque attritus (including brown matter)	6
Fusain	19

The coal is microbanded and consists of layers of anthraxylon alternating with layers or lenticles of fusain and opaque attritus. The anthraxylon contains a considerable amount of material showing indications of cell structure, in particular lenticles of tissue with thick compressed cell walls which are dark red in thin section. The opaque attritus consists mainly of brown matter. Fusain occurs as bands or lenticles in which the cell structure is frequently poorly preserved. It is opaque in the thinnest sections. Where the cell structure is well preserved the cell cavities are usually empty, in contrast to some of the other coals, in which they are occupied by mineral matter. The translucent attritus consists of microspores and cuticle fragments together with fragments of leaf degradation matter.

Coal from a seam discovered in a prospecting shaft in the Cooneana estate, portion 283, parish of Goodna, has been sectioned but detailed study was not possible on account of the weathered nature of the available specimens. The coal is microbanded and the translucent attritus, like that of most of the other Bundamba coals, consists mainly of cuticular matter. Stratigraphical evidence indicates that this seam is on a lower horizon than any seams worked in the Blackstone stage.

(b) THE COAL SEAMS OF THE TIVOLI STAGE.

(i) General Features.

Specimens of coal from these seams, as mined in the North Ipswich area, are readily distinguishable from the coals of the Blackstone stage by their greater friability. This property is well developed in the bright coals which, under the action of weathering or pressure, tend to disintegrate into small fragments of subcubical shape. On account of this the preparation of thin sections has been rendered extremely difficult, and thus a detailed study of coal from each seam has not been possible. Sufficient has been done, however, to indicate the general features to which all the seams that have been sectioned conform. Although they resemble the Blackstone coals in the general proportions of the most abundant constituents—anthraxylon and opaque attritus—they differ so distinctly in several other petrographic features as to suggest that they originated under somewhat different environmental conditions. The principal differences are as follows:—

(1) Translucent attritus, as represented by spores and cuticular matter, is absent or present in such small proportions as to escape detection in all the sections studied. In the Blackstone coals such material forms a small but constantly-present proportion of the seams.

(2) Fusain, if present, occurs in disintegrated fragments without evident cell structure and is indistinguishable from the opaque matter of the attritus. The attritus as a whole is opaque in sections of normal thickness and assumes a brown, homogeneous appearance in very thin sections. In some layers it reaches a sufficiently high proportion to produce coal of the semisplint or splint type. Such layers are duller and less friable than the bright coal, which contains a high proportion of anthraxylon.

(3) The anthraxylon bands are distinctive in that they are practically structureless in thin section, in contrast to those of the Blackstone coals in which cell structure, often well preserved, is usually recognizable. This indicates that the plant matter was in an advanced state of decomposition and maceration in the peat stage and suggests that the Tivoli coals originated under conditions especially favourable to such decomposition and maceration.

(4) Mineral matter in these coals is associated very largely with the attritus, which forms a high proportion of the duller splint or semisplint bands, so that the proportion of these bands is a macroscopic guide to the ash content of the coal.

(ii) The Tivoli Seam.

Coal from the Tivoli seam (Rothwell Haigh Colliery) is conspicuously banded and consists of bright, friable layers alternating with duller harder bands. Microscopic examination shows that the dull layers have the constituents present in proportions typical of the semisplint coal type. The coal types, bright and semisplint, are present in the following proportions:—

	Per cent.
Bright coal	63
Semisplint coal	37

The bright coal consists almost entirely of anthraxylon which is nearly all structureless with the exception of rare tissues of the resin duct type which have evidently resisted maceration. The semisplint coal consists of anthraxylon and brown-opaque attritus in layers which are finely banded to microbanded. The anthraxylon bands are straight compact and smooth, and in this respect are typical of this coal type. The proportions of the constituents in the semisplint coal are:—

	Per cent.
Anthraxylon	51
Brown-opaque attritus	49

The proportions of the constituents in a typical specimen of coal are thus:—

	Per cent.
Anthraxylon	82
Brown-opaque attritus	18

Mineral matter occurs in the form of particles of small average grain size associated almost entirely with the attritus. The proportion varies in different layers of the attritus and in some it is so high as to indicate the presence of a shale lenticle. The proportion of mineral matter in one thin section was estimated to be 8 per cent.

(iii) The Benley Seam.

The coal sectioned from this seam came from Thompson's tunnel. It is uniformly bright in appearance and quite friable. Some of the anthraxylon occurs as thick, lenticular, uniformly lustrous bands which are brighter than the remainder of the coal. The anthraxylon is typically structureless in thin section and the brown-opaque attritus contains a high proportion of mineral matter. The proportions of the constituents in the specimens studied are:—

	Per cent.
Anthraxylon	88
Brown-opaque attritus	12

(iv) The Garden Seam.

The only specimens of coal which could be obtained from this seam were collected from a dump from the Dolly Varden tunnel, Tivoli. All the coal was weathered, but some relatively less weathered specimens of bright coal were collected and sectioned with some difficulty. Microscopic study of thin sections of this material has furnished some data on the mechanism of weathering (de Jersey, 1944, p. 95). In the proportions of the constituents the coal is fairly similar to that of the Benley seam, described above. The anthraxylon is entirely structureless and the brown-opaque attritus, which occurs in lenticular patches, is high in sedimentary mineral matter.

3. CHEMICAL CLASSIFICATION OF THE IPSWICH COALS.

The most recent classification of coals on a chemical basis is that of the American Society for Testing Materials (1938). This classification has been accepted very widely in the United States and in England and is adopted here. Its bases are the fixed carbon content, calculated on a dry mineral-matter-free basis, and the calorific value (expressed in B.T.U.) calculated to a moist mineral-matter-free basis. An account of this classification is given by Raistrick and Marshall (1939, pp. 273-275).

For the purpose of placing a coal in the A.S.T.M. classification it is thus necessary to express the fixed carbon content on a dry, mineral-matter-free basis. For this purpose the Parr formulae are recommended as they have been found to apply to a wide variety of coals with less error than most of the other proposed formulae. The relevant formulae (Sprunk and others, 1940, p. 33) are:—

Mineral matter, per cent .. .. $= 1.08A - 0.55S$

$$\text{Volatile matter, dry Mm-free coal basis, per cent.} = \frac{100\ (\text{V.M.} - 0.08A - 0.4S)}{100 - \text{Mm}}$$

Fixed carbon, dry Mm-free coal basis, per cent = 100 — volatile matter dry Mm-free coal basis, per cent.

where

Mm = Mineral matter, per cent.;
A = ash, per cent.;
S = total sulphur, per cent.;
V.M. = volatile matter, per cent.;

all expressed on the dry coal basis.

For the seams of the Blackstone stage, the percentages of fixed carbon (dry, mineral-matter-free coal basis), calculated from five published analyses which include sulphur determinations (Dunstan, 1913, pp. 273-275), are:—65·1, 66·1, 68·0, 68·2, 69.0. These analyses thus indicate an approximate range from 65 to 69 per cent. fixed carbon and the classification of the coals as high-volatile bituminous. For the remaining analyses no sulphur determinations are available, but assuming a sulphur content of 1 per cent., the majority of the calculated values give fixed carbon values within the above range and support the classification of the majority of the coals as high volatile bituminous.

For the seams of the Tivoli stage, the percentages of fixed carbon (dry, mineral-matter-free coal basis), calculated from six published analyses which include sulphur determinations (Dunstan, 1913, p. 275), are:—71·3, 71·8, 71·9, 73·0, 73·6, 75·0. An approximate range from 71 to 75 per cent. fixed carbon is thus indicated and the coals are classifiable as medium-volatile bituminous. As in the case of the Blackstone coals, the remaining analyses are in support of this classification.

During the course of a recent survey of the Ipswich coalfield, numerous analyses have been carried out, which, when available, may lead to some modification of the above values. According to A. K. Denmead,* Government Geologist, who carried out this survey, these analyses indicate (1) a greater range in fixed carbon values for the coals of the Blackstone stage, so that a few of the samples would fall in the medium-volatile bituminous group, and (2) that the Tivoli coals east of Sandy Creek have fixed carbon values approaching those of the Blackstone coals.

From the recalculated analyses, it thus becomes evident that, with some exceptions, the coal seams fall into two chemical groups corresponding to the two stratigraphical divisions of the Ipswich Series. Microscopic study has shown that the differences are not entirely due to differences in petrographic composition; the proportion of volatile-rich spores and cuticles in the Blackstone coals would account for less than one-fourth of the difference between the average values for each group. Variation in the proportion of opaque attritus similarly would not explain the chemical differences as the available evidence indicates that the North Ipswich coals are predominantly bright coals, splint forming a minor element in both groups. Consequently an explanation of the differences in rank must be related primarily to differences in the degree of

* Verbal Communication.

metamorphic evolution of the coal seams in the two stages of the series. The available data suggest that regional metamorphism was of greatest intensity in the North Ipswich area, and diminished in intensity to the east of Sandy Creek and towards the south-east in the direction of the Bundamba mining district. However, the data for study of rank variation are very incomplete, as only proximate analyses are available; ultimate analyses, interpreted by graphs of carbon against oxygen content (dry, ash- and sulphur-free basis) are much more valuable for this purpose.

4. A COMPARISON WITH SOME OTHER QUEENSLAND COALS.

Preliminary work which the writer has carried out on the Blair Athol and Callide coals (de Jersey, 1944, p. 95) has supplied data for a comparison of these coals with the Ipswich coals. No detailed study has been made of material from either of these coalfields, as the coal seams in question are especially thick, and a detailed quantitative study of their petrography would necessitate the preparation of thin sections at intervals throughout the entire thickness of each seam. Sufficient has been done, however, to indicate the type and general features in each case.

The specimens of Blair Athol coal studied came from the Big Seam, of average thickness 60 feet and maximum thickness 93 feet (Reid, 1936, p. 339), which is now being worked by open-cut methods. Coal from this seam is high- to medium-volatile bituminous in rank. All the specimens examined are splint coal, so that the seam appears to be largely, or entirely, composed of this coal type. Microspores are fairly abundant in the thin sections studied and lenticular patches of fusain with well preserved cell structure are present. The coal thus differs in type from the Ipswich coals, in that it is a splint coal while the latter are predominantly bright coals. The abundance of spores distinguishes it from many of the Ipswich splint layers, from which it also differs in its low mineral matter content.

The Callide coal seam studied is 21 feet thick and consists of splint coal with the exception of one thin layer of bright coal. The coal contains only a small proportion of spores and cuticular matter, and in this respect resembles the Ipswich coals. It has a higher anthraxylon content than the Ipswich splints studied, and has a higher mineral matter content than that of the Blair Athol coal.

5. UTILIZATION OF THE IPSWICH COALS.

(a) COAL PREPARATION.

There is a growing realization in industry that coal is a raw material which may be prepared for use in various forms and for various purposes. The primary process of coal preparation involves the separation of the combustible portion of the coal from the accompanying mineral matter and comes under the general term "coal washing." This process is of particular importance in the Ipswich coalfield as many of the seams contain a high proportion of mineral matter and to produce a low-ash fuel suitable for steam-raising, gas production and other uses, washing is necessitated. Washing is affected to a considerable extent by the form in which mineral matter occurs in coal seams. This is directly determinable by microscopic study. Stutzer and Noé state (1940, p. 76):—"An essential preliminary to the solution of any preparation problem is the microscopic examination of the coal. One may then observe the texture of the banding whether coarse or fine, and then determine the amount of crushing necessary for the separation of the various ingredients. Microscopic control of the preparation process is also necessary to deliver specific varieties of fuel. All coal preparation processes should be under microscopic control, but particularly those still in an experimental stage."

Mineral matter occurring in the coal seams consists of:—(1) The thicker persistent shale bands and (2) mineral matter closely associated with the coal. The former are mechanically separable from the coal in mining and are omitted when sampling a seam face for chemical analysis. Such analyses thus represent the best coal that can be produced by mining at the locality sampled. They show an ash content of over 15 per cent. for many of the seams and this represents class (2) of mineral matter outlined above. This mineral matter consists of (*a*) shale streaks and lenticles frequently associated with splint coal; (*b*) particles of mineral matter finely disseminated through the bright coals, and, more abundantly through the splint layers. These are principally composed of finely divided clay minerals, such as kaolinite, together with quartz grains and rounded particles of pyrite; (*c*) secondary mineral matter occupying the cleats, joints and shrinkage cracks of bright coal; (*d*) the inherent mineral matter of the plant degradation material, which is not observable in the coal under the microscope, and cannot be removed by cleaning. According to Raistrick and Marshall (1939, p. 198), the ash yield from this source "is very low, usually of the order of 1 per cent. or less."

Of these modes of occurrence, the particles of mineral matter included under (*b*) are usually too small in grain size to be separable from the coal by the normal crushing process preparatory to washing. Mineral matter included under (*a*) and (*c*) is, however, largely separable in this manner. Thus a coal in which there is a high proportion of finely disseminated mineral particles will have only a portion of its ash content removed by cleaning. Such coals from the Ipswich seams include those studied from the Rob Roy, Bergin's and Bluff seams in the Blackstone stage; in the Four-Foot seam the splint layers contain the highest proportion of mineral matter. In the Tivoli seams the ash content is due to particles constantly associated with the attritus; only the part of such material which consists of larger particles would ordinarily be separable by washing. So constant is this association as to suggest that an effectual cleaning process for these coals would be one which would remove the attrital layers, together with their sedimentary mineral matter. This naturally leads to the question of separating various constituents of coal on a commercial basis.

Stutzer and Noé (1940, pp. 76-80) give a review of pre-war research in Germany on the separation of coal constituents. They state (pp. 76, 77):—"The cleaning of coal, by separating it from accompanying impurities, has been carried on for a long time. To-day the process of coal preparation has gone a step farther by effecting the concentration of the individual ingredients. . . . . Thus the removal of fusain is desirable since it is often very troublesome if left in the coal, whereas vitrain* enrichment produces a more strongly cokable but highly swelling coal. . . . . The best and most practicable means of improving most bituminous coals, after removal of the mineral matter by washing, is by removal of the fusain, if it is present in large quantities. In Lower Silesia this is often done by flotation. The remaining coal is then divided into a portion rich in vitrain, for coking purposes, and into a part rich in durain,* for tar and gas production. Similar processes are being tried out for the Upper Silesia coal and for the free-burning gas-coal of Westphalia."

Removal of fusain would effect an improvement in the Ipswich coals rich in this constituent, such as the coal from Aberdare Extended Colliery. The physical properties of the opaque and semi-opaque attritus are closer to those of fusain than any of the other constituents and such material may also be separable by flotation processes, and, if so, would effect a further improvement in quality.

* Vitrain is equivalent to anthraxylon and durain to splint coal in the American terminology.

(b) GAS PRODUCTION.

The suitability of coal for use in the production of coal gas is related to both rank and type. Raistrick and Marshall state (1939, p. 151):—"A wide variety of coals have been used in the manufacture of coal gas, but generally speaking the most suitable have a volatile content between 30 per cent. and 40 per cent. A.F.D. (ash-free dry) and an oxygen : hydrogen ratio of approximately 2." It is evident that the Blackstone coals satisfy these requirements and are more suitable for gas making than the Tivoli coals, which, as a group, are lower in volatile matter.

The quality of coal mined for gas production is improved by cleaning processes; the washed coal has a higher volatile content and the ash content of the coke remaining of the carbonization is reduced. It is also possible, by selective mining, to produce coal with a higher gas yield. Work in the United States has shown that bright coals tend to produce a greater volume of gas in carbonization than splint coals. Also the calorific value of the gas produced from bright coals tends to be higher than for splint coals (Sprunk and others, 1940, p. 49). Thus the gas yield of coal produced for this purpose would be increased by rejecting the splint layers of the seam in mining, or by using coal from a seam consisting largely of bright coal. On application to the Blair Athol coal these data indicate that this coal in which the splint type predominates would have a low gas yield and would be relatively unsuitable for gas-making purposes.

(c) HYDROGENATION.

The Bergius process is now recognised as the most widely applicable process for the production of liquid fuels from coal. Considerable experimental work has been carried out in recent years in England and the United States, especially with regard to testing the suitability of various coals for hydrogenation. It has been found that microscopic study provides a reliable guide to the suitability of a coal for hydrogenation, and as the reactions of the various constituents to treatment have been worked out in detail, it is possible to apply these results to the Queensland coals studied.

The most recent published work is that of the United States Bureau of Mines, carried out in the experimental hydrogenation plant at Pittsburgh. The results, quoted from two recent papers, are as follows:—"The results show that all common constituents of low or intermediate-rank coals, except fusain and opaque attritus, are liquefied almost completely; that is, with little or no organic residue. Fusain and opaque attritus contain about 75 to 95 per cent. and 20 to 60 per cent. resistant matter, respectively." (Storch and others, 1941, pp. 5, 6.) "The Bureau of Mines small-scale hydrogenation tests on the banded constituents of coal have led to the general conclusion that bright coals are more suitable than splint coals for conversion into liquid products. . . . The hydrogenation results indicate that with respect to liquefaction yield the coal constituents may be classed conveniently into two groups. The first group of easily liquefiable constituents includes anthraxylon and all organic constituents of the translucent attritus such as woody degradation matter, leaves, spores-pollens-cuticles, resins and algae. This statement applies to coals containing less than 89 per cent. carbon (moisture- and ash-free basis); additional data are required to determine the hydrogenation characteristics of the above constituents in extremely high-rank coals that are known to give lower liquefaction yield."

"The second group of constituents is more difficult to liquefy. One of the constituents is opaque attritus, the characterizing constituent of splint coals; the other is fusain. . . . . By means of petrographic methods, residue yield can be predicted with a fair degree of accuracy. . . . . The predicted yield was estimated by assuming that the different constituents would give the following percentage yield of residue:—Ash and fusain, 100; opaque attritus, 38; all other constituents, 0." (Sprunk and others, 1940, pp. 54, 57.)

It is thus evident that the splint coals from Blair Athol and Callide are less suitable for hydrogenation than bright coals. The Ipswich coals are predominantly bright coals in type, so that the organic matter is in a form suitable for hydrogenation; however, many of the seams are high in disseminated mineral matter which is non-liquefiable. The Aberdare Seam appears to have the most suitable coal for hydrogenation purposes; the coal has a relatively low ash content, and has a low proportion of opaque attritus and fusain, which are difficult to liquefy. The average ash, opaque attritus, and fusain contents are 10, 12, and 1·5 per cent., indicating a residue yield of the order of 16 per cent. A comparison with the American coals on this basis suggests a crude oil yield of the order of 120 gallons per ton of coal, a figure which compares favourably with those obtained in tests on American coals. It is also noteworthy that the Ipswich coals have a low moisture content, of the order of 1 to 3 per cent.; the higher moisture content of the Callide and Blair Athol coals would tend to lower their hydrogenation oil yield.

6. SUMMARY AND CONCLUSIONS.

The purpose of this investigation has been to ascertain the features common to the coals as a whole by a general survey of material from a number of horizons and localities rather than to make a detailed study of a restricted number of seam columns. Such general features are evidently related to distinctive environmental conditions prevailing during the deposition of the coal seams of the Ipswich Series. They are as follows:—

1. In type the Ipswich coals are predominantly bright coals; splint coal usually occurs as thin layers aggregating a small proportion of the total thickness of the seams.

2. The bright coals of the Blackstone stage, which have been studied in most detail, have an average anthraxylon content of the order of 75 per cent. The remaining organic matter of the coal consists mainly of opaque attritus and fusain; spores and cuticular matter, which comprise the translucent attritus, constitute a small proportion, of the order of 1 to 2 per cent. of the seams.

3. The splint layers of the seams usually contain much sedimentary mineral matter, and frequently grade into shale bands in the seam sections.

4. Available data indicate that the Tivoli seams differ in several petrographic characters from those of the Blackstone Stage. These differences suggest that they originated under somewhat different environmental conditions.

5. In rank the Ipswich coals comprise both the medium- and high-volatile bituminous groups. The Tivoli coals, as developed in the North Ipswich area, are, as a group, higher in rank than the Blackstone coals and are mainly classifiable as medium-volatile bituminous.

6. In consequence of their predominant type (bright) the Ipswich coals are more suitable for utilization in gas production and hydrogenation than the splint coals of the Blair Athol and Callide coalfields.

Although sufficient has been done to provide a basis for comparison with other Queensland coals there is considerable scope for further detailed study. Detailed examination of complete seam columns would supply data bearing on the distribution of mineral matter and consequently on washing processes, which will probably become more important in future utilization of the Ipswich coals. In addition further investigation of rank variation in terms of ultimate analyses would assist in interpretation of the metamorphic evolution of the coals.

7. ACKNOWLEDGEMENTS.

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DESCRIPTION OF PLATES.

Plate 1.

Thin section of coal from Bluff Seam, Box Flat Extended No. 5 Colliery. The predominant constituent is anthraxylon occurring in translucent lenticular bands which range in thickness from finely banded to microbanded. In the lower left-hand corner of the photograph is a lenticular fragment of tissue in transverse section; the other tissues forming the anthraxylon are cut in longitudinal section and some show indications of pitting. The remainder of the coal consists of brown-opaque attritus and fusain, and mineral matter represented by hazy white spots. x 200.

Plate 2.

Thin section of coal from Bluff seam, Box Flat Extended No. 5 Colliery. Opaque and semi-opaque attritus (dark layers) forms a higher proportion of the coal than that shown in Plate 1 and many of the anthraxylon bands are thin and irregular. Mineral matter is more abundant than in Plate 1. x 200.

Plate 3.

Figure 1: Thin section of bright coal from Aberdare Seam, Hart's Aberdare Colliery. Crossed nicols. This photograph demonstrates the anisotropism of the anthraxylon bands. The dark material is opaque and semi-opaque attritus; thin cuticular fragments and microspores are also present. x 200.

Figure 2: Thin section of bright coal from Four-foot Seam, Bonnie Dundee No. 2 Colliery. Material formed from leaf tissues occupies the middle part of the photograph and is associated with cuticles, which appear in thin section, as thin, highly translucent, bright yellow bands. x 200.

Plate 4.

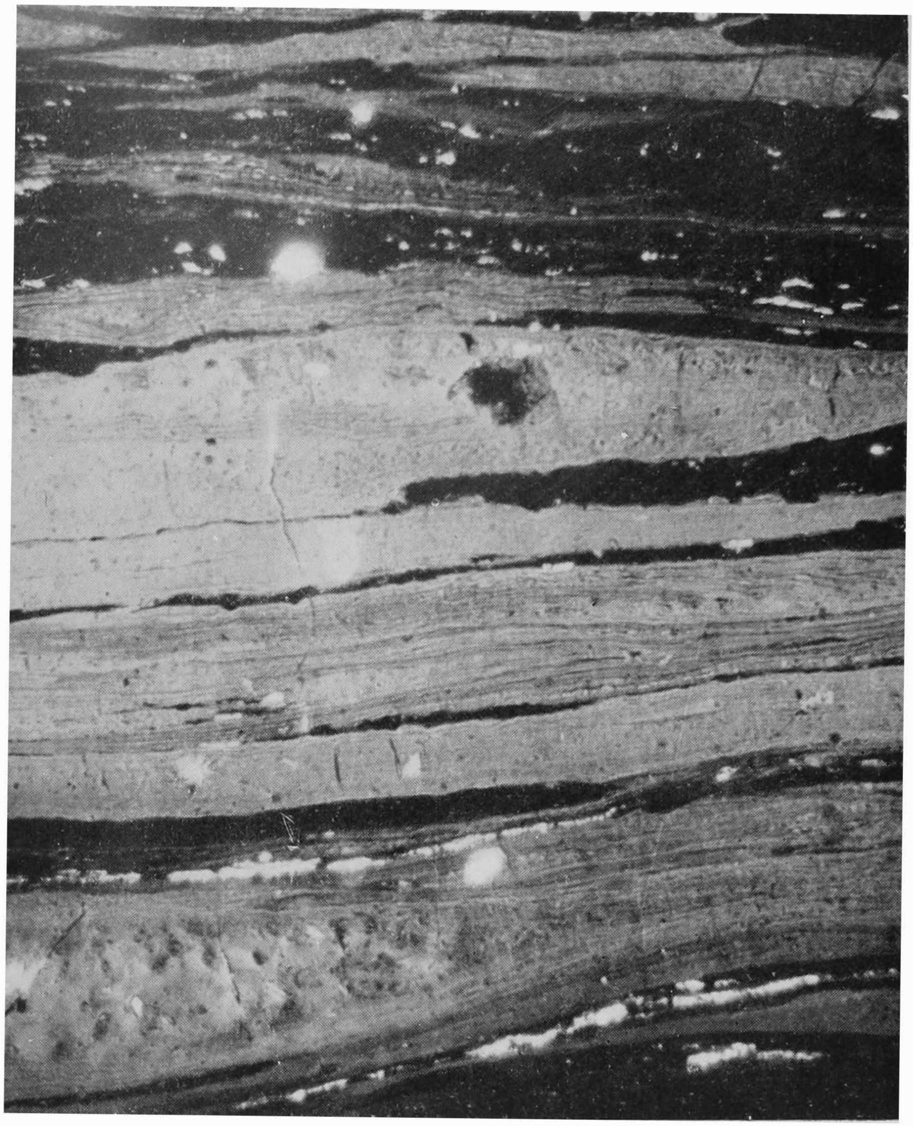
Figure 1: Thin section of bright coal from New Found Out Seam, Aberdare Extended Colliery. The lenticular area of anthraxylon has cell structure preserved; in the thin section the cell walls are dark red in colour and become more elongate at one end of the patch of tissue. x 200.

Figure 2: Thin section of bright coal from Four-foot Seam, Bonnie Dundee No. 2 Colliery. The anthraxylon in the middle of the photograph shows well preserved cell structure; the cells are thick-walled and the cell cavities are filled with darker material. All the cells are much compressed. Also present are microspores and cuticular fragments; the dark material is largely brown opaque attritus. x 330.

Plate 5.

Figure 1: Thin section of bright coal from Rob Roy Seam, Rylance No. 3 Colliery. The prominent feature of the photograph is a thin-walled megaspore. The remainder of the coal is largely anthraxylon, with some opaque and semi-opaque attritus, a few microspores and particles of mineral matter (hazy white spots). x 200.

Figure 2: Thin section of splint coal from Four-foot Seam, Noble Vale No. 3 Colliery, No. 1 Tunnel. Anthraxylon occurs in thin irregular strands; the attritus consists of brown matter, translucent humic matter and microspores. Particles of mineral matter are represented by hazy white spots. x 200.



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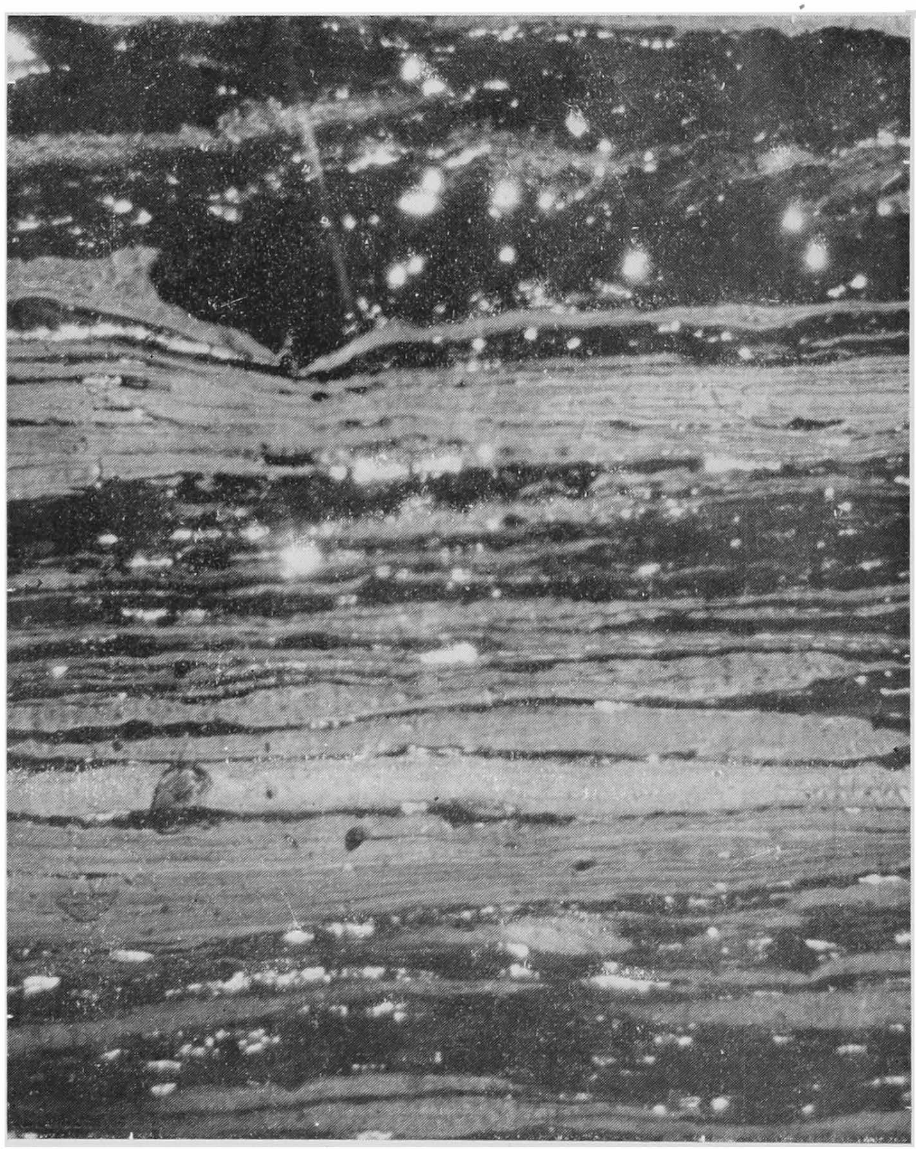

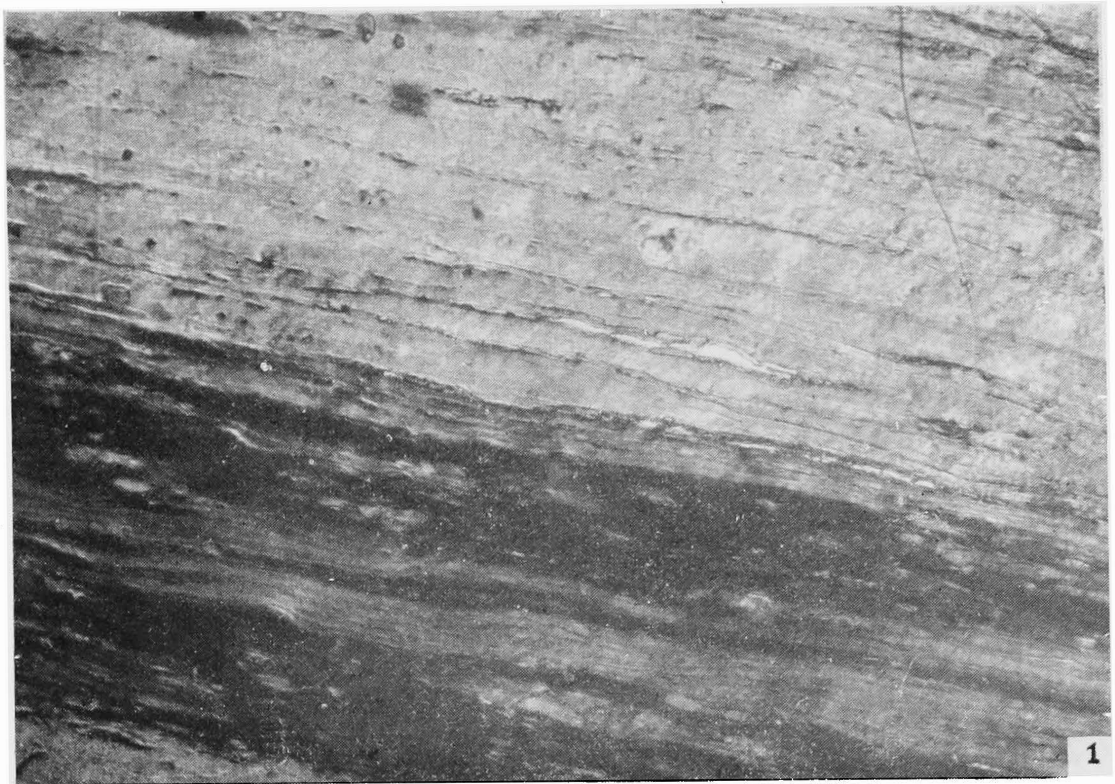

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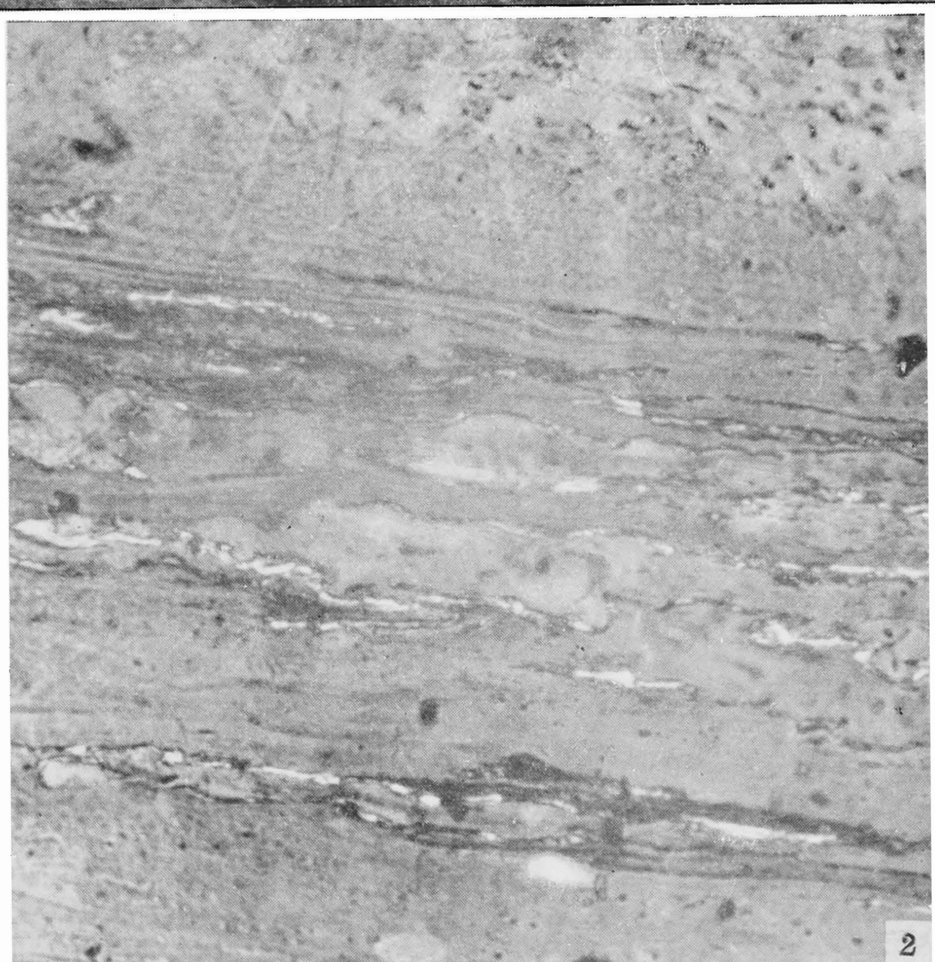

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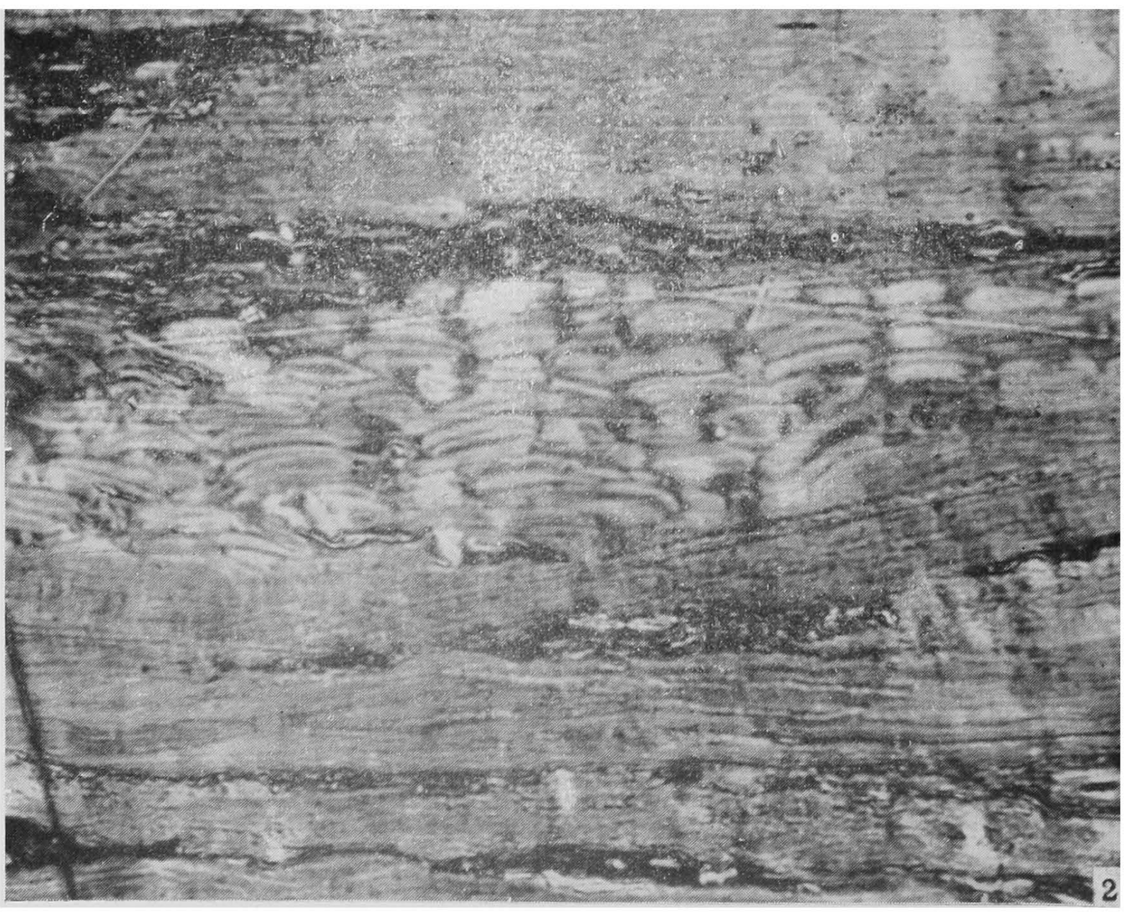

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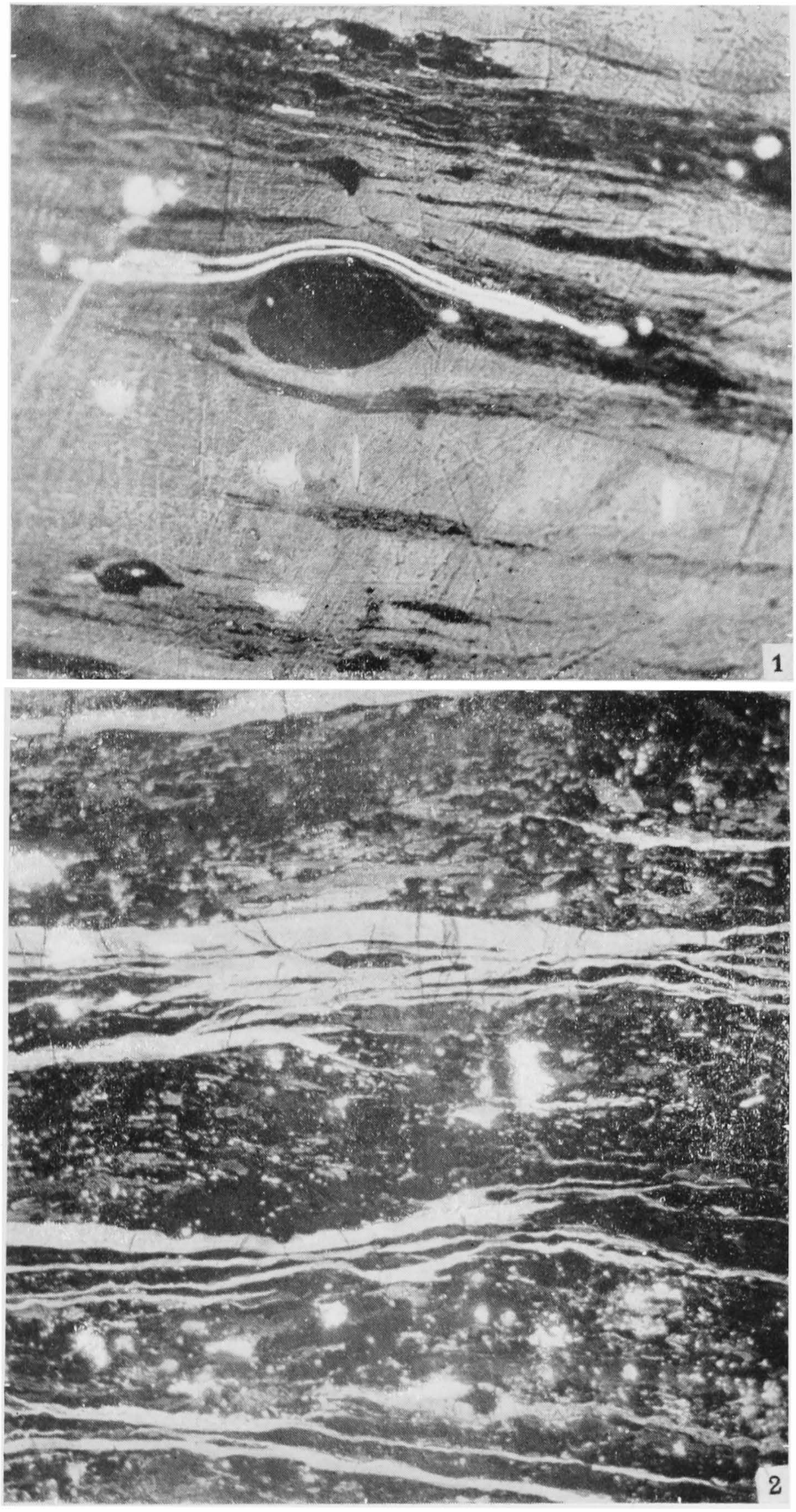

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